PRAMANA — journal of physics

Vol. 69, No. 4
October 2007
pp. 521–531

Charmless nonleptonic B decays into scalar and pseudoscalar mesons

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MS received 22 March 2007; revised 30 July 2007; accepted 8 August 2007

Abstract. The charmless nonleptonic decay modes $B \to f_0 K(\pi)$ involving a scalar and a pseudoscalar meson in the final state are studied. The scalar meson f_0 is considered as a $q\bar{q}$ state, as favored by some recent studies. Using the generalized factorization approach, the branching ratios and CP violation parameters are computed for these modes. The form factors are calculated using the results from relativistic light front quark model and the ISGW2 model. It is found that the direct CP violation parameters in these modes are small. However, the obtained branching ratios are not in agreement with the experimental data. Therefore, these modes may be considered as possible probes for new physics.

Keywords. Nonleptonic B decays; scalar mesons; CP violation.

PACS Nos 13.25.Hw; 13.20.He; 11.30.Er

1. Introduction

Weak B decays play a very valuable role as they provide insights into the standard model (SM) world of CP violation, testing the Kobayashi–Maskawa (KM) mechanism, which allows CP violation in the SM of electroweak interactions, determining the CKM unitarity angles and exploring models beyond the SM. The two B-factories BaBar at SLAC and Belle at KEK have started a new era in the exploration of CP violation. The main objective of these factories is to test the SM and also to look for possible signals of new physics (NP). They are providing us with huge data and we expect many exciting years in B physics and CP violation. With this in mind, we see that B physics has many important contributions to particle physics.

Charmless two-body nonleptonic B decays can be described by a tree-level spectator diagram or a one-loop penguin diagram. Therefore, such decays are usually divided into three classes: (a) decays having both tree and penguin (QCD and EW) contributions, (b) decays having only tree contributions, and (c) decays having only penguin contributions. These decays can also have contributions from W-exchange, annihilation and vertical loop processes but their contributions are expected to be small.

Measurement of rare hadronic B decays, induced by FCNC transitions $b \to s, d$ which are loop suppressed in the SM can help us to understand and test QCD and EW penguin mechanism and also to look for any NP contribution as they are sensitive to physics beyond the SM. In this paper, the decay modes which are dominated by loop-induced $b \to s\bar{q}q$ ($q = u, d, s$) penguins and which also have a small $b \to u$ tree level transition are studied. The annihilation contributions are neglected here as they are considered to be small.

The theoretical analysis of nonleptonic B decays requires the use of a low-energy effective Hamiltonian which is the starting point for the phenomenology of weak decays of hadrons. It is calculated using the operator product expansion (OPE) and has the generic form:

$$H_{\text{eff}} = \frac{G_{\text{F}}}{\sqrt{2}} V_{\text{CKM}} \sum_i C_i(\mu) O_i(\mu) \ , \tag{1}$$

where G_{F} is the Fermi constant, O_i are the relevant local operators or effective vertices in the effective theory, V_{CKM} are the CKM factors in the SM, C_i are the Wilson coefficients or coupling constants associated with the effective vertices and μ denotes an appropriate renormalization scale.

The transition matrix elements between the initial and final states are of the form:

$$\langle f|H_{\text{eff}}|i\rangle \propto \sum_k C_k(\mu) \langle f|O_k(\mu)|i\rangle \ . \tag{2}$$

The OPE separates the short-distance contributions to the transition amplitudes from the long-distance ones which are described by the perturbative Wilson coefficient functions $C_k(\mu)$ and non-perturbative hadronic matrix elements $\langle f|O_k(\mu)|i\rangle$, respectively.

In this paper, the two-body decay of B meson to the scalar mesons $f_0(980, 1370, 1500)$ and the pseudoscalar mesons $K(\pi)$ are considered. Till date, there has been no common consensus on the structure of these scalar mesons. There has been a lot of debate on this issue. Even though the low-energy hadron phenomenology has been successful in terms of the constituent quark model, the structure of scalar mesons is still not clear and therefore they are not understood with certainty.

There are suggestions to interpret $f_0(980)$ as $K\bar{K}$ molecular states [1], four quark states [2] and normal $q\bar{q}$ states [3]. But, the data of $D_s^+ \to f_0\pi^+$ [4] and $\phi \to f_0\gamma$ [5,6] favor the $q\bar{q}$ model for $f_0(980)$ with its copious production in D_s^+ decays via its $s\bar{s}$ component. There are also experimental evidences [7] that it is not a pure $s\bar{s}$ state but a mixture of the strange and non-strange quark content, i.e., it is a mixture of $s\bar{s}$ and $n\bar{n} \equiv (u\bar{u} + d\bar{d})/\sqrt{2}$. Therefore, the flavor content of $f_0(980)$ is taken to be $f_0 = n\bar{n}\sin\theta + s\bar{s}\cos\theta$, where θ is the mixing angle. In [8], the $f_0 - \sigma$ mixing angle is discussed in detail where it was found that θ lies in the ranges of $25° < \theta < 40°$ and $140° < \theta < 165°$. In this paper, the above structure for $f_0(980)$ with dominant $s\bar{s}$ content is followed.

The scalar $f_0(1500)$ also has an uncertain structure. In [9], the scalar mesons above 1 GeV are identified as a conventional $q\bar{q}$ nonet with some possible glue content. In this paper, we assume $f_0(1500)$ to be dominated by the quarkonium content as in [10], i.e., $f_0(1500) = n\bar{n}\sin\theta + s\bar{s}\cos\theta$. The scalar $f_0(1370)$ flavor content is taken as in [11], i.e., $f_0(1370) = s\bar{s}\sin\theta + n\bar{n}\cos\theta$. The dependence of the branching ratios on θ is shown as plots for the modes involving $f_0(1370)$ and $f_0(1500)$.

The B decay modes involving $f_0(980)$ have been studied in the QCD factorization in [12,13] and in the PQCD approach in [10,14]. In [10], $f_0(1500)$ is also studied. Hadronic decays involving $f_0(980)$ are also studied in charmed decays in [8]. In this paper, the generalized factorization approach is followed for analysing the decay modes $B \to f_0(980, 1370, 1500)K(\pi)$.

We calculate the branching ratios and CP asymmetries for the relevant modes using the form factors from the results of relativistic covariant light-front quark model [15] and the ISGW2 model [16]. The CP asymmetries are calculated using the expressions in [17]. It is found that the branching ratios are not in agreement with the experimental data. The CP violation parameters are also negligibly small. Therefore, these B decay modes involving the scalar particles f_0 may be considered as possible probes for new physics.

The paper is organized as follows. In §2, the factorized amplitudes for each mode, in the framework of generalized factorization, and the relevant expressions for branching ratios and CP asymmetries are given. Section 3 contains the input parameters, §4 the results and the last section contains the conclusion.

2. Factorized amplitudes, branching ratios and CP asymmetries

2.1 $B \to f_0 K(\pi)$ *decay amplitudes*

As mentioned in the Introduction, we use an effective Hamiltonian for the theoretical analysis of nonleptonic weak B decays. The relevant effective Hamiltonian for our charmless nonleptonic B decays is given as

$$H_{\rm eff}(\Delta B = 1) = \frac{G_{\rm F}}{\sqrt{2}}\Bigg[V_{ub}V_{uq}^*\Big\{C_1(\mu)O_1^u(\mu) + C_2(\mu)O_2^u(\mu)\Big\} - V_{tb}V_{tq}^*\Big\{\sum_{i=3}^{10} C_i(\mu)O_i(\mu)\Big\}\Bigg] , \tag{3}$$

where $q = d, s$ and $O_1^u = (\bar{u}b)_{V-A}(\bar{q}u)_{V-A}$, $O_2^u = (\bar{u}_\alpha b_\beta)_{V-A}(\bar{q}_\beta u_\alpha)_{V-A}$, $O_{3(5)} = (\bar{q}b)_{V-A}\sum_{q'}(\bar{q}'q')_{V-A(V+A)}$, $O_{4(6)} = (\bar{q}_\alpha b_\beta)_{V-A}\sum_{q'}(\bar{q}'_\beta q'_\alpha)_{V-A(V+A)}$, $O_{7(9)} = \frac{3}{2}(\bar{q}b)_{V-A}\sum_{q'} e_{q'}(\bar{q}'q')_{V+A(V-A)}$, $O_{8(10)} = \frac{3}{2}(\bar{q}_\alpha b_\beta)_{V-A}\sum_{q'} e_{q'}(\bar{q}'_\beta q'_\alpha)_{V+A(V-A)}$.

The factorization approximation is used to evaluate the hadronic matrix elements. In this approach, one can write these elements in terms of the decay constants and form factors which are parametrized as

$$\langle 0|A^\mu|K(\pi)(k)\rangle = i f_{K(\pi)}k^\mu , \quad \langle 0|q\bar{q}|f_0\rangle = m_{f_0}\bar{f}_{f_0}^q , \tag{4}$$

$$\langle K(\pi)(k)|(V-A)_\mu|B(P)\rangle = \left[(P+k)_\mu - \left(\frac{m_B^2 - m_{K(\pi)}^2}{q^2}\right)q_\mu\right]F_1^{BK(\pi)}(q^2) + \left(\frac{m_B^2 - m_{K(\pi)}^2}{q^2}\right)q_\mu F_0^{BK(\pi)}(q^2)\ , \tag{5}$$

$$\langle f_0(q)|(V-A)_\mu|B(P)\rangle = i\left[(P+q)_\mu - \left(\frac{m_B^2 - m_{f_0}^2}{k^2}\right)k_\mu\right]F_1^{Bf_0}(k^2) + \left(\frac{m_B^2 - m_{f_0}^2}{k^2}\right)k_\mu F_0^{Bf_0}(k^2), \tag{6}$$

where V and A denote the vector and axial-vector currents, respectively. Furthermore, $f_{K(\pi)}$ and $\bar{f}_{f_0}$(scalar decay constant) are the decay constants of $K(\pi)$ and f_0 mesons, respectively. The vector decay constant for f_0 is zero owing to charge conjugation invariance or conservation of vector current. $F_{0,1}(q^2)$ are the form factors and P, q, k are the momenta of $B, f_0, K(\pi)$ mesons satisfying the relation $q = P-k$.

On using the effective Hamiltonian (3), the factorizable decay amplitudes can be obtained for all the modes within the generalized factorization scheme. The decay mode $B^- \to f_0(980)\ K^-$ receives contributions from $b \to u$ tree and $b \to s\bar{q}q$ $(q = u, s)$ penguins within the SM. The annihilation diagrams behave as (f_B/m_B) in comparison with the tree and penguin contributions and are also helicity suppressed by $(m_{u,d,s}/m_B)$ since the B mesons are pseudoscalars [18]. As such, these contributions are neglected in all the modes considered here. Thus, the amplitude for this charged mode is given as

$$\mathcal{A}(B^- \to f_0(980)K^-) = \frac{G_\mathrm{F}}{\sqrt{2}}\Big[-V_{ub}V_{us}^* a_1 X_2 + V_{tb}V_{ts}^*\Big\{(2a_6 - a_8)X_1 + (a_4 + a_{10})X_2 - 2(a_6 + a_8)Y_1\Big\}\Big]\ , \tag{7}$$

where

$$X_1 = \left[\frac{(m_B^2 - m_K^2)}{(m_b - m_s)}\right]F_0^{BK}(m_{f_0}^2)m_{f_0}\bar{f}_{f_0}\ ,$$
$$X_2 = (m_B^2 - m_{f_0}^2)F_0^{Bf_0}(m_{K^-}^2)f_{K^-}\ ,$$
$$Y_1 = \frac{(m_B^2 - m_{f_0}^2)m_{K^-}^2 F_0^{Bf_0}(m_{K^-}^2)f_{K^-}}{(m_b + m_u)(m_u + m_s)}\ , \tag{8}$$

and the a_i's are the combinations of Wilson coefficients given by

$$a_{2i-1} = C_{2i-1} + \frac{1}{N_\mathrm{c}}C_{2i}\ ,\quad a_{2i} = C_{2i} + \frac{1}{N_\mathrm{c}}C_{2i-1}\ , \tag{9}$$

where N_c is the number of colors.

The neutral mode $B^0 \to f_0(980)K^0$ receives contributions only from $b \to s\bar{q}q$ $(q = s, d)$ penguins. Therefore, the transition amplitude reads as

$$\mathcal{A}(B^0 \to f_0(980)K^0)$$
$$= \frac{G_{\rm F}}{\sqrt{2}} V_{tb}V_{ts}^* \left[(2a_6 - a_8)X_3 + \left(a_4 - \frac{a_{10}}{2}\right) X_4 - 2\left(a_6 - \frac{a_8}{2}\right) Y_2 \right] , \qquad (10)$$

where

$$X_3 = \left[\frac{(m_{B^0}^2 - m_{K^0}^2)}{(m_b - m_s)}\right] F_0^{BK^0}(m_{f_0}^2) m_{f_0} \bar{f}_{f_0} ,$$
$$X_4 = (m_B^2 - m_{f_0}^2) F_0^{Bf_0}(m_{K^0}^2) f_{K^0} ,$$
$$Y_2 = \frac{(m_B^2 - m_{f_0}^2) m_{K^0}^2 F_0^{Bf_0}(m_{K^0}^2) f_{K^0}}{(m_b + m_d)(m_d + m_s)}. \qquad (11)$$

The mode $B^- \to f_0(980)\pi^-$ receives contributions only from the $n\bar{n}$ component of f_0. The transition amplitude therefore has the form

$$\mathcal{A}(B^- \to f_0(980)\pi^-) = \frac{G_{\rm F}}{\sqrt{2}} \Big[- V_{ub}V_{ud}^* a_1 X_5 + V_{tb}V_{td}^* \Big\{ (a_4 + a_{10}) X_5$$
$$+ (2a_6 - a_8) X_6 + 2(a_6 + a_8) Y_3 \Big\} \Big] , \qquad (12)$$

where

$$X_5 = (m_B^2 - m_{f_0}^2) F_0^{Bf_0}(m_\pi^2) f_\pi ,$$
$$X_6 = \frac{(m_B^2 - m_\pi^2) F_0^{B\pi}(m_{f_0}^2) m_{f0} \bar{f}_{f_0}}{(m_b - m_d)} ,$$
$$Y_3 = \frac{m_\pi^2 X_5}{(m_b + m_u)(m_d + m_u)}. \qquad (13)$$

Here, the flavor wave function for $f_0(980)$ is taken as $s\bar{s}\cos\theta + n\bar{n}\sin\theta$ where $n\bar{n} = (u\bar{u} + d\bar{d})/\sqrt{2}$. The θ dependence of the form factor and decay constant involving f_0 is, therefore, given as

$$F_0^{B^- f_0} = \frac{1}{\sqrt{2}} \sin\theta F_0^{B^- f_0^{u\bar{u}}}, \qquad F_0^{B^0 f_0} = \frac{1}{\sqrt{2}} \sin\theta F_0^{B^0 f_0^{d\bar{d}}} \qquad (14)$$

and

$$\bar{f}_{f_0}^n = \frac{1}{\sqrt{2}} \sin\theta \tilde{f}_{f_0}^n, \qquad \bar{f}_{f_0}^s = \cos\theta \tilde{f}_{f_0}^s. \qquad (15)$$

Now, the modes involving $f_0(1370, 1500)$ are briefly discussed. As the mixing angle for these scalars is not well-known, the variation of the branching ratio with this angle (denoted by θ) is shown in plots for both decay processes. These decays have similar amplitudes as those for $B \to f_0(980)K(\pi)$. The decay amplitudes for $B^- \to f_0(1370, 1500)K^-$ are as in (7) and that for $B^- \to f_0(1370)\pi^-$ as in (12). The flavor wave function for $f_0(1370)$ is taken as opposite to that of $f_0(980)$, i.e., $s\bar{s}\sin\theta + n\bar{n}\cos\theta$ following [11]. For $f_0(1500)$, the flavor wave function is taken as that of $f_0(980)$.

2.2 *Branching ratios and CP asymmetry parameters*

The branching ratios are obtained from the above decay amplitudes as

$$\mathrm{BR}(B \to f_0 K(\pi)) = \frac{|p_c|\tau_B}{8\pi m_B^2} \, |\mathcal{A}(B \to f_0 K(\pi))|^2 \,, \tag{16}$$

where $|p_c|$ is the c.m. momentum of the final mesons, τ_B is the lifetime of the B meson, m_B is the mass of the decaying B meson and $\mathcal{A}(B \to f_0 K(\pi))$ is the factorized amplitude.

In [8], the experimental implications for the mixing angle for $f_0(980)$ have been discussed in detail and shown that θ lies in the ranges of $25^\circ < \theta < 40^\circ$ and $140^\circ < \theta < 165^\circ$. Here, we therefore calculate the branching ratios and CP asymmetry parameters only for the modes involving $f_0(980)$ and take the mixing angle as 153° as obtained from QCD sum rules and f_0 meson results [21], which is well within the range obtained in [8]. The branching ratios for the modes involving $f_0(1370, 1500)$ are plotted as functions of θ only.

Now, the expressions for the CP asymmetry parameters are presented. The process $B^- \to f_0(980)K(\pi)^-$ has only direct CP violation. The amplitude for this process is written as

$$\begin{aligned} A(B^+ \to f_0 K(\pi)^+) &= \lambda_u^* |A_u| \mathrm{e}^{i\delta_u} + \lambda_t^* |A_t| \mathrm{e}^{i\delta_t} \,, \\ A(B^- \to f_0 K(\pi)^-) &= \lambda_u |A_u| \mathrm{e}^{i\delta_u} + \lambda_t |A_t| \mathrm{e}^{i\delta_t} \,, \end{aligned} \tag{17}$$

where $\lambda_q = V_{qb} V_{qs}^* (q = u, t)$ denotes the product of CKM matrix elements and contains the weak phase information. γ is the weak phase in λ_u^*, δ_u and δ_t are the strong phases corresponding to A_u and A_t, respectively, which are the contributions arising from the current operators proportional to λ_u and λ_t.

Therefore, for the charged decay modes $B \to f_0(980)K(\pi)$, the CP violating rate asymmetry is defined in [17] as

$$\begin{aligned} A_{\mathrm{CP}} &= \frac{\Gamma(B^+ \to f_0 K(\pi)^+) - \Gamma(B^- \to f_0 K(\pi)^-)}{\Gamma(B^+ \to f_0 K(\pi)^+) + \Gamma(B^- \to f_0 K(\pi)^-)} \\ &= \frac{2r \sin\gamma \sin(\delta_u - \delta_t)}{1 + r^2 - 2r \cos\gamma \cos(\delta_u - \delta_t)} \,, \end{aligned} \tag{18}$$

where $r = |\lambda_u A_u / \lambda_t A_t|$.

The neutral B meson decays have both direct and mixing-induced components. If we consider the mesons B^0 and $\bar{B}^0$ decaying into a CP eigenstate f_{CP} (here, $f_{\mathrm{CP}} = f_0 K_S$ with CP eigenvalue +1), then we can write down the time-dependent CP asymmetry for $B \to f_0 K_S$ as

$$\begin{aligned} A_{f_0 K_S}(t) &= \frac{\Gamma(B^0(t) \to f_0 K_S) - \Gamma(\bar{B}^0(t) \to f_0 K_S)}{\Gamma(B^0(t) \to f_0 K_S) + \Gamma(\bar{B}^0(t) \to f_0 K_S)} \\ &= C_{f_0 K_S} \cos(\Delta M_{B_d} t) - S_{f_0 K_S} \sin(\Delta M_{B_d} t) \,, \end{aligned} \tag{19}$$

where

$$C_{f_0K_S} = \frac{1-|\lambda|^2}{1+|\lambda|^2}\ , \qquad S_{f_0K_S} = \frac{2\mathrm{Im}(\lambda)}{1+|\lambda|^2} \tag{20}$$

are the direct and mixing-induced CP asymmetries, respectively. The parameter λ is given as

$$\lambda = \frac{q}{p}\frac{\mathcal{A}(\bar{B}^0 \to f_0K_S)}{\mathcal{A}(B^0 \to f_0K_S)}\ , \tag{21}$$

where q and p are the mixing parameters and are given in terms of the CKM matrix elements in the SM as

$$\frac{q}{p} = \frac{V_{tb}^*V_{td}}{V_{tb}V_{td}^*} \sim \exp(-2i\beta). \tag{22}$$

The amplitude for $\bar{B}^0 \to f_0K_S$ is written symbolically as

$$A(\bar{B}^0 \to f_0K_S) = \lambda_t A_t\ , \tag{23}$$

where $\lambda_t = V_{tb}V_{ts}^*$ is real in the SM.

3. Input parameters

For our numerical calculations of branching ratios and CP asymmetries, we use the particle masses and lifetimes of B mesons from [7]. The current quark masses are taken as $m_b = 4.2$ GeV, $m_s = 95$ MeV, $m_u = 3.0$ MeV and $m_d = 6.0$ MeV. The Wolfenstein parameters used for the CKM matrix elements are given as $\lambda = 0.2205$, $A = 0.815$, $\rho = 0.175$ and $\eta = 0.370$ [19]. Therefore,

$$V_{ub} = A\lambda^3(\rho - i\eta), \quad V_{us} = \lambda, \quad V_{ud} = (1 - \tfrac{1}{2}\lambda^2),$$

$$V_{tb} = 1, \quad V_{ts} = -A\lambda^2, \quad V_{td} = A\lambda^3(1 - \bar{\rho} - i\bar{\eta}),$$

where

$$\bar{\rho} = \rho(1 - \tfrac{1}{2}\lambda^2), \qquad \bar{\eta} = \eta(1 - \tfrac{1}{2}\lambda^2).$$

The effective coefficients a_i's used are also taken from [19].

For the form factors $F_0^{B^- f_0^{u\bar{u}}}$ and $F_0^{B^0 f_0^{d\bar{d}}}$ involved in the transition $B \to f_0$, the ISGW2 model [16] is used. They are calculated at m_K^2 or m_π^2 depending on the decay mode involving K or π and are given as

$$\begin{aligned}
&F_0^{B^- f_0(980)^{u\bar{u}}}(m_{K^-}^2) = 0.103\ , \quad F_0^{B^0 f_0(980)^{d\bar{d}}}(m_{K^0}^2) = 0.103\ ,\\
&F_0^{B^- f_0(1370)^{u\bar{u}}}(m_{K^-}^2) = 0.112\ , \quad F_0^{B^- f_0(980)^{u\bar{u}}}(m_{\pi^-}^2) = 0.103\ ,\\
&F_0^{B^- f_0(1370)^{u\bar{u}}}(m_{\pi^-}^2) = 0.112\ , \quad F_0^{B^- f_0(1500)^{u\bar{u}}}(m_{K^-}^2) = 0.114\ .
\end{aligned} \tag{24}$$

For the form factors involved in the transition $B \to K(\pi)$, the results from the relativistic covariant light front quark model [15] are taken where the form factor is parametrized as

$$F(q^2) = \frac{F(0)}{1 - a(q^2/m_B^2) + b(q^2/m_B^2)^2}\ , \tag{25}$$

where for $B \to \pi$ transition, $F_0^{B\pi}(0) = 0.25$, $a = 0.84$, $b = 0.10$ and for $B \to K$ transition, $F_0^{BK}(0) = 0.35$, $a = 0.71$, $b = 0.04$.

The decay constants used are $f_K = 160$ MeV and $f_\pi = 130.7$ MeV. The decay constants $\tilde{f}_{f_0(980)}$ and $\tilde{f}_{f_0(1500)}$ are taken from [13] (here, $\tilde{f}_{f_0}^s = \tilde{f}_{f_0}^n$) where $\tilde{f}_{f_0(980)}(2.1\text{ GeV}) = 460$ MeV and $\tilde{f}_{f_0(1500)}(2.1\text{ GeV}) = 315$ MeV. The decay constant for $f_0(1370)$ is taken as the same as that for $f_0(980)$.

4. Results

In this section, the results for branching ratios and CP asymmetries are given. The experimental values for the modes $B^{-(0)} \to f_0(980)K^{-(0)}$ are taken from [17] and for $B^- \to f_0(980)\pi^-$ from [20] and are given as

$$\begin{aligned}
&\mathrm{BR}(B^+ \to f_0(980)K^+) = (17.38 \pm 3.47) \times 10^{-6}\ ,\\
&\mathrm{BR}(B^0 \to f_0(980)K^0) = (11.26 \pm 2.52) \times 10^{-6}\ ,\\
&\mathrm{BR}(B^+ \to f_0(980)\pi^+) < 3.0 \times 10^{-6}\ .
\end{aligned} \tag{26}$$

Using the value $\theta = 153^\circ$ as obtained from QCD sum rules and f_0 meson results [21], which is well within the range obtained in [8], the branching ratios obtained in this paper for the modes $B \to f_0 K(\pi)$ are

$$\begin{aligned}
&\mathrm{BR}(B^- \to f_0(980)K^-) = 7.78 \times 10^{-6}\ ,\\
&\mathrm{BR}(B^0 \to f_0(980)K^0) = 7.18 \times 10^{-6}\ ,\\
&\mathrm{BR}(B^- \to f_0(980)\pi^-) = 0.12 \times 10^{-6}\ .
\end{aligned} \tag{27}$$

It is seen that these values are well below the experimental ones given in (26). Therefore, these decays may be considered as an indirect hint for the possible existence of new physics. For the processes involving $f_0(1370, 1500)$, the variation of branching ratio with the mixing angle θ is shown as plots in figures 1, 2 and 3. Since the flavor wave function for $f_0(1370)$ is taken as opposite to that of $f_0(980)$, i.e., $s\bar{s}\sin\theta + n\bar{n}\cos\theta$, the plot for $f_0(1370)K$, which has dominant $s\bar{s}$ contribution, has the form as shown in figure 1 and for the mode $f_0(1370)\pi$, which has only $n\bar{n}$ contribution, the form is opposite, as shown in figure 2. It is found that the branching ratio for the mode $B^- \to f_0(1370)K^-$ lies within the range (0.15–9.09) $\times 10^{-6}$, for $B^- \to f_0(1370)\pi^-$ within the range (2.80×10^{-13}–0.70×10^{-6}) and that for $B^- \to f_0(1500)K^-$ within the range (0.07–10.4) $\times 10^{-6}$.

The CP asymmetries obtained for the relevant modes are

$$\begin{aligned}
&A_{\mathrm{CP}}(B^- \to f_0(980)K^-) = -0.023\ ,\\
&A_{\mathrm{CP}}(B^- \to f_0(980)\pi^-) = -0.386\ .
\end{aligned} \tag{28}$$

For the color suppressed (and Cabibbo suppressed) tree contributions to the mode $B^0 \to f_0(980)K^0$, the decay constant f_{f_0} defined by $\langle f_0(p)|V_\mu|0\rangle = f_{f_0} p_\mu$ is zero

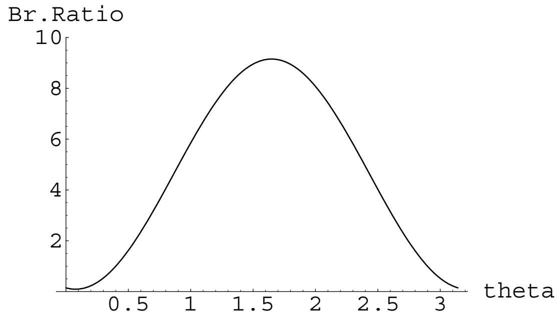

Figure 1. Branching ratio (in units of 10^{-6}) for the process $B^- \to f_0(1370)K^-$ vs. the mixing angle θ.

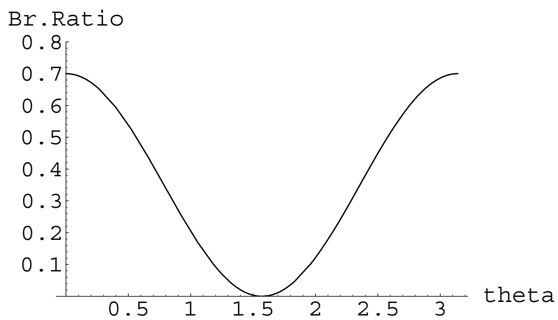

Figure 2. Branching ratio (in units of 10^{-6}) for the process $B^- \to f_0(1370)\pi^-$ vs. the mixing angle θ.

as the scalar meson f_0 cannot be produced via the vector current owing to charge conjugation invariance or conservation of vector current. Therefore, there is only one amplitude contributing to this decay mode which is the penguin amplitude. As such, the mixing-induced CP asymmetry for $B^0 \to f_0(980)K^0$ is the same as that for the decay process $B \to \psi K_S$ but opposite in sign, i.e., $-\sin 2\beta$ and the direct CP asymmetry turns out to be identically zero.

5. Conclusion

In this paper, the rare decay modes $B \to f_0 K(\pi)$ dominated by the loop-induced $b \to s\bar{q}q$ $(q = s, u, d)$ involving scalars and pseudoscalars have been studied. The f_0 meson is considered as a $q\bar{q}$ ($s\bar{s}$ and $n\bar{n}$) state motivated by recent studies although its structure is not well established till now. The generalized factorization approach was used here and the ISGW2 and the relativistic covariant light front quark models were used for obtaining the form factors. It was found that the branching ratios for the processes involving the scalar $f_0(980)$ do not match with current experimental data. So these modes may be considered as possible probes for new physics. The

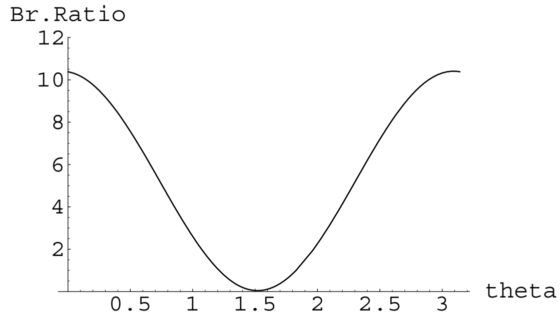

Figure 3. Branching ratio (in units of 10^{-6}) for the process $B^- \to f_0(1500)K^-$ vs. the mixing angle θ.

new physics could perhaps explain the discrepancy between data and theory. As the mixing angle for the processes involving $f_0(1370, 1500)$ is not very well-known, the variation of the branching ratios with the mixing angle is shown as plots only. The CP asymmetries for the modes $B^- \to f_0(980)K(\pi)^-$ were also calculated. It was found that for $B^- \to f_0(980)\pi^-$, the direct CP asymmetry is large, $A_{\rm CP} \sim (-38\%)$, as r (the ratio of tree to penguin contributions) is $\sim$1.62. This is an interesting observation and can be checked/confirmed in upcoming experiments such as the LHC. For $B^- \to f_0(980)K^-$, the direct CP violation was found to be $\sim(-2\%)$ (here, $r \sim 0.04$). The direct CP asymmetry for $B^0 \to f_0(980)K^0$ is zero as it has only a penguin contribution and the tree contributions are suppressed. The mixing-induced CP asymmetry is $-\sin 2\beta$, same as the one for $B \to \psi K_S$ but with opposite sign. New physics contributions could probably change the observations. If the structure of the scalar mesons are very well established, then we can understand their nature properly and the modes considered here can be important grounds for doing so and to look for new physics beyond the standard model.

Acknowledgement

The author would would like to acknowledge the Council of Scientific and Industrial Research, Government of India, for financial support and would like to thank Dr. Rukmani Mohanta for guidance.

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